Institute of Paper Science and Technology
Atlanta, Georgia

IPST Technical Paper Series Number 798

Impulse Drying of Board Grades: Pilot Production Trials

D.I. Orloff, P.M. Phelan, J.W. Crouse

June 1999

Submitted to
1999 TAPPI Engineering/Process & Product Quality Conference
September 12-16
Anaheim, California

INSTITUTE OF PAPER SCIENCE AND TECHNOLOGY
PURPOSE AND MISSIONS

The Institute of Paper Science and Technology is an independent graduate school, research organization, and information center for science and technology mainly concerned with manufacture and uses of pulp, paper, paperboard, and other forest products and byproducts. Established in 1929, the Institute provides research and information services to the wood, fiber, and allied industries in a unique partnership between education and business. The Institute is supported by 52 North American companies. The purpose of the Institute is fulfilled through four missions, which are:

- to provide a multidisciplinary education to students who advance the science and technology of the industry and who rise into leadership positions within the industry;
- to conduct and foster research that creates knowledge to satisfy the technological needs of the industry;
- to serve as a key global resource for the acquisition, assessment, and dissemination of industry information, providing critically important information to decision-makers at all levels of the industry; and
- to aggressively seek out technological opportunities and facilitate the transfer and implementation of those technologies in collaboration with industry partners.

ACCREDITATION

The Institute of Paper Science and Technology is accredited by the Commission on Colleges of the Southern Association of Colleges and Schools to award the Master of Science and Doctor of Philosophy degrees.

NOTICE AND DISCLAIMER

IMPULSE DRYING OF BOARD GRADES: PILOT PRODUCTION TRIALS

David. I. Orloff
Professor and Director, Engineering Division
Institute of Paper Science and Technology
500 10th Street N.W., Atlanta, GA 30318

Paul M. Phelan
Associate Scientist, Engineering Division
Institute of Paper Science and Technology
500 10th Street N.W., Atlanta, GA 30318

Jere W. Crouse
Consultant
JWC CNSLG
4207 E. Circlewood Drive
Beloit, WI 53511

ABSTRACT

In September 1998, the Institute and Beloit Corporation were successful in impulse drying 161 g/m^2 (33#) linerboard on a one-meter wide pilot paper machine. This was the first time that impulse-dried linerboard had been reeled. The demonstration included a comparison of impulse drying to single-felted wet pressing.

Test results show that impulse drying, when compared to single-felted wet pressing, yields significant increases in press dryness, CD STFI, CD ring crush, and Mullen burst. The impulse-dried liner was also considerably smoother than the wet-pressed controls.

The demonstration also showed that runnability issues, such as start-up procedures, as well as operational issues, such as roll sticking and sheet delamination, have been resolved.

BACKGROUND

Impulse drying has the promise of reducing capital costs, increasing machine productivity, reducing fiber use, reducing energy use, and improving paper physical properties. The Institute of Paper Science and Technology has been working to commercialize the impulse drying of board grades since the mid-1980s. In the early 1990s, the research focus was to control the physical aspects of the web to make it less susceptible to delamination, or to modify press roll surface properties to control heat flux. More recently [1,2,3], work has been undertaken to control the cause of delamination, i.e., flash vaporization.

In a unique experiment [1], Institute researchers showed that application of increased ambient pressure during and after the nip opening process inhibits sheet delamination. This result had significant implications for impulse drying commercialization. The work suggested that by sufficiently increasing the ambient pressure at nip opening, press roll surface temperature could be increased without inducing web delamination. In a general way, the work pointed out the importance of properly designing and controlling the nip opening process.

In subsequent research [2], temperature distributions were measured within layers of impulse-dried sheets during nip opening to various ambient pressures. Using these data and thermodynamic reasoning, pressure profiles were determined within the web. Based on these profiles, the hypothesis that delamination was caused by an imbalance of internal and external sheet pressure was tested. The results supported the view that delamination occurs when the pressure difference across the sheet is too high, and the buildup of internal pressure disrupts the sheet.

While opening the nip to ambient pressures in excess of one atmosphere may eventually prove to be practical, other methods that may be easier to implement were sought. In particular, subsequent laboratory experiments [3] showed that delamination could be inhibited by properly controlling the load applied to the sheet as the nip opens. The experiment consisted of identifying nip opening load conditions that would be sufficient to suppress the delamination of linerboard handsheets. The work demonstrated that delamination could be inhibited by applying a controlled decompression during nip opening.

Utilizing these discoveries, the Institute of Paper Science and Technology and the Beloit Corporation embarked on a joint project to develop impulse drying for application to board grades. The objectives of the project were to develop the necessary technology, to demonstrate the technology on a pilot paper machine, and to conduct converting trials at a commercial box plant.

In a recent paper [4], Institute and Beloit personnel described the process modifications that allow impulse drying of board grades to become commercially feasible and reported the results of initial pilot paper-machine experiments. These initial pilot paper-machine experiments confirmed that the ramp decompression concept could be used to increase critical impulse drying temperature, thus opening the operating window of the technology. A specially designed adjustable ramp shoe allowed on-the-fly adjustment of nip decompression, which facilitated optimization. In addition, a combination of a specially designed press roll surface and the use of a TET doctor helped to eliminate picking and control sticking. Venting of the nip and blanket groove geometry were also found to be important.

EXPERIMENTAL

In September 1998, success was achieved in producing 161 g linerboard on Beloit's #4 pilot paper machine. This is the first time that impulse dried linerboard had been reeled. The demonstration included a comparison of impulse drying to single-felted wet pressing. Figure 1 shows a schematic diagram of the press section of the pilot paper machine. The machine consisted of a gap former, bi-nip press, a shoe press, a dryer section, calender, and reel. The shoe press was of a closed design that could function as a single-felted wet press or as an impulse dryer. The shoe press was outfitted with a 0.23-m-long standard shoe followed by a 0.11-m-long ramp shoe. The pressure profile of the ramp shoe could be adjusted "on-the-fly" until the ramp profile was optimized to achieve the highest press roll temperature without experiencing sheet delamination. Figure 2 shows the ramp shoe pressure profile centered in the CD direction and measured from the position of peak load pressure. The profile is similar to that used in previously reported experiments on Beloit's No. 2 pilot paper machine [4].

Table I shows the chronology of the linerboard production trials. Reels of impulse-dried liner were produced at two press roll temperatures and two calender loadings on the first day. Press dryness measurements were also taken. On the second day, reels of single-felted wet-pressed liner at two calender loadings were produced. Measurements of press dryness were taken and calendering experiments were conducted to determine the impact of calender loading on linerboard properties. The second day was also used to repeat, over a range of press roll temperatures, the impulse drying that was accomplished on the first day.

Table II shows the paper-machine conditions that were recorded for the two days of the trial. Freeness was targeted at 650 ml CSF for both days. Note that the freeness during the first day was 613 ml CSF and during the second day was 669 ml CSF. This difference in refining level was inadvertent and was only discovered at the end of the second day of trials.

Table III shows web solids as measured after the couch, after the flatbox (between the couch and the bi-nip), and after the bi-nip press that was ahead of the impulse dryer.

Detailed measurements of the physical properties of the impulse-dried linerboard made at various press roll surface temperatures on the first and second day showed that they were slightly different. These differences are explored in the physical property development section of this paper.

ECONOMICS OF ENERGY USAGE

The electric power usage of the induction heating system was measured during the impulse drying experiments on both days. On the first day, while the reels were being produced, the induction heating system drew 495 kW at a roll temperature of 255°C and 531 kW at a roll temperature of 271°C.

Figure 3 shows the electric power usage as a function of average press roll surface temperature as measured on both days of the linerboard trials. Note that the energy usage on Day #1, during the reel production phase of the trial, was lower than on Day #2, when short duration experiments were conducted at increasing temperature. Note also that the later data are less consistent. This comparison suggests that the press roll was not in equilibrium during the later experiments.

Based on electric power usage data from Day #1, 171.5 kW-hr/ton were used when the roll was set at a target roll temperature of 260°C. Based on an estimated electrical power cost of $0.03/kW-hr, our roll heating cost was $5.14/ton. The estimated cost savings in reduced steam usage (assuming a 3.8-point increase in dryness at the press section and a $2.83 /million Btu steam cost) was $1.18/ton. Since some of the improvement in physical properties was due to increased refining, the estimated electric power costs associated with this incremental refining was $0.79/ton (based on an estimate of 26.3 kW-hr/ton to refine from 669 ml CSF to 613 ml CSF). Hence, the net increase in energy costs was about $4.75/ton. Therefore, to make this application viable, there must be fiber savings and productivity improvements that justify a $4.75/ton energy cost penalty.

PRESS SOLIDS

Figure 4 shows press solids outgoing from the impulse dryer as a function of target roll surface temperature for experiments performed on the first and second day of the trials. Also included are the outgoing press solids for the wet pressing performed on Day #2 of the trials. As will be shown in the physical property development section, impulse drying temperatures of as high as 260°C could be reached without the sheet showing signs of sheet delamination. Hence, impulse drying could be used to increase outgoing solids by about 3.3 to 4.0 points of dryness as compared to the wet-pressed control.

PHYSICAL PROPERTY DEVELOPMENT

Preliminary Measurements

Linerboard properties were measured at Beloit's paper testing laboratory. In these measurements, there was no attempt to distinguish cross-directional machine variations in paper physical properties. In addition, physical property indexes are based on average conditioned basis weight and no confidence limits were available. Based on the reported results, Figures 5 and 6 show CD STFI compression index and CD ring crush index, respectively, plotted against target roll surface temperature. Comparing impulse drying (from the first day of the trial) to single-felted wet pressing (from the second day of the trial), there is [7] an 18% improvement in CD STFI and a 7% improvement in CD ring crush at the critical temperature of 260°C. The drop in strength above 260°C is due to delamination. Part of the strength increase is due to daily refining differences.

Finalized Measurements

Detailed measurements of linerboard properties were undertaken at the Institute of Paper Science and Technology. In these measurements, the linerboard was tested in three cross-directional lanes (operator lane, center, and drive lane). Test frequency was increased so that it would reduce the error bars (95% confidence limits) to an acceptable level. In addition, physical property indexes are based on oven-dried weights of individual test strips.

The cross-directional profile of the reels of linerboard produced on the first and second day of the trial was explored. Figure 7 shows CD SFTI index and Figure 8 shows MD STFI index, both as measured in the drive, center, and operator lanes of the single-felted wet-pressed and impulse-dried linerboard. The drive lane is presented as a white bar, the center lane is reported as a black bar, and the operator lane is shown as a gray bar. In Figure 7 the operator lane was normally stronger than the drive lane, which was in turn stronger than the center lane. In Figure 8 the operator lane was stronger than the center lane, which was stronger than the drive lane. This could be an artifact of cross directional nonuniformities (pressure, moisture, fiber orientation, and basis weight) associated with the setup of the paper machine. Figure 9 shows the MD/CD tensile ratio as measured in each of the three lanes. The web was consistently MD oriented (with an MD/CD tensile ratio of about 2.5) and tended to be more MD oriented in the center lane. The fact that CD STFI index tended to be lowest in the center lane suggests the need to also measure properties of corrugated board in edge and center lanes.

The data have been averaged over the web width in the remaining figures showing linerboard properties. In previous work, it was found that use of zd-ultrasonics is an effective and sensitive test for sheet delamination. Figure 10 shows the zd-specific elastic modulus of wet-pressed and impulse-dried linerboard as a function of the target roll surface temperature. Note that there was a drop-off in modulus at roll temperatures above 260°C. This suggests a critical impulse drying temperature of 260°C for the experiments.

Figures 11 and 12 show the CD STFI index and CD ring crush index, respectively, as plotted against target roll surface temperature. Both of these properties increase with increased roll temperature. It is important to compare these properties in a range of roll temperatures from 240 to 260°C on both days of the trial. It is observed that the strength of the impulse-dried liner produced on the first day of the trial tended to be stronger than that produced at a similar temperature on the second day. This can also be seen in Figure 13, where CD STFI index is plotted as a function of apparent density. Hence, the difference is attributed to increased refining on the first day.

While CD STFI compression strength and CD ring crush influence the ultimate strength of corrugated board, linerboard smoothness is most important as a predictor of printability [8]. In the present work, the smoothness of the roll side of the linerboard was measured as Bendtsen roughness and as Emveco roughness. Figure 14 reports the micro average Emveco roughness of the hot roll side of liner produced during our trials. Figure 15 reports the micro deviation Emveco roughness. Linerboard with a micro average of less than 0.25 and a micro deviation of less than 100 will print well [9]. In both cases the roughness in both the CD and MD were recorded. It is observed that the samples are always smoother in the MD. It is also observed that the samples become smoother as the roll surface temperature was increased and when the liner is calendered. The key finding is that impulse drying significantly reduced the roughness of the linerboard and that impulse-dried liner would not need to be calendered.

In summary, Table IV shows the percent improvement in critical physical properties of the reels of impulse dried linerboard as compared to the appropriate wet-pressed controls. Impulse drying was found to increase CD STFI by about 10%, CD ring crush by between 11 to 14%, and Mullen burst by between 13 and 20%. Hence, basis weight reductions of 10% or more may be possible.

The convertability of the linerboard produced during these trials has been compared to that of a commercial linerboard in an accompanying paper [10].

REFERENCES

1. Orloff, D. I., Patterson, T., Krause, A. M., "Opening the Operating Window of Impulse Drying – Part I. The Effect of Ambient Pressure at Nip Opening," Tappi J. 81(7):113 (1998).

2. Orloff, D. I., Patterson, T., Parviainen, P. M., "Opening the Operating Window of Impulse Drying - Part II. Pressure Differential as a Source Of Delamination," Tappi J. 81(8):195 (1998).

3. Orloff, D. I., Patterson, T., Phelan, P., Rudman, I., "Opening the Operating Window of Impulse Drying – Part III. Controlled Decompression Experiments," Tappi J. 81(9):159 (1998).

4. Orloff, D. I. and Crouse, J. W., "Impulse Drying: Status of the Pilot-Scale Research Program," 1998 TAPPI Proceedings of the International Engineering Conference, Book 3, pp. 879, September 13-17, 1998.

5. Orloff, D.I., and Sobczynski, S.F., "Impulse Drying Pilot Press Demonstration: Ceramic Surfaces Inhibit Delamination," Paper Technology 34(10):24(1993).

6. Soczka, E., personal communication, December 1998, Institute of Paper Science and Technology, Atlanta, Georgia.

7. Orloff, D. I., "Impulse Drying of Board Grades: An Emerging Technology," PaperAge, 114(12):22 (1998).

8. Orloff, D.I., Challas, J., and Rudman, I., "Flexographic Printing of Linerboard," TAGA Proceedings, 1:277(1995).

9. Miller, B. W., "Determining Printability of Linerboard Manufactured for Post Print Converters Using Water-based Flexographic Ink," Proceedings of the 1997 TAPPI Process and Product Quality Conference and Trade Fair, pp. 135, Sept. 28-Oct. 3, 1997.

10. Orloff, D. I., Phelan, P. M., and Challas, J., "Impulse Drying of Board Grades: Converting Trials," Presented at the 1999 TAPPI Engineering/Process & Product Quality Conference, Anaheim, Sept. 12-16, 1999.

ACKNOWLEDGEMENTS

The author would like to thank the Member Companies of the Institute of Paper Science and Technology, the Beloit Corporation, and the U.S. Department of Energy (through Grant No. DOE/CE/40738) for supporting this research. The author would also like to thank David Lange of Beloit Corporation and Charles McWilliams of Tekscan, Inc. for their contributions to this work.

TABLES

Table I. Chronology of Linerboard Production Trials

Day #	Reel Speed, m/min	Press Mode	Press Load, kN/m	Target Roll Temperature, °C	Calender Loading, kN/m	Comments
1	381	I D	1050	246	0 (open)	4 Reels produced
				246	35	2 Reels produced
				260	0 (open)	4 Reels produced
				205 to 262	n.a.	Dryness samples
2	381	SFWP	1050	n.a.	10-45	Reel samples
					0 (open)	4 Reels produced
					35	4 Reels produced
					n.a	Dryness samples
2	381	I D	1050	204 to 288	0 (open)	Reel samples
	381				n.a	Dryness samples
	314				n.a	Dryness samples

Table II. Typical Production Conditions

Condition	Day 1	Day 2
Machine Chest Temp., °C	58	63
Freeness, ml CSF	613	669
WRV	2.15	2.05
Target Cond. Basis Wt, gsm	160	160
Jet-to-Wire Ratio	1.22	1.22
1st Press Load, kN/m	105	105
2nd Press Load, kN/m	140	140
Calender Temp., °C	121	121
Target Reel Moisture, %	5	5

Table III. Typical Press Solids

Condition	Day 1	Day 2
After Couch, % Solids	20.2	21.0
After Flatbox, % Solids	23.5	24.5
After Bi-Nip, % Solids	40.4	42.0

Table IV. Percentage Improvement in Linerboard Properties
(Compared to the Wet Pressed Controls)

Impulse-Drying Temperature, °C	Calendering	Improvement CD STFI, %	Improvement CD Ring Crush, %	Improvement Mullen Burst, %
246	no	9.8	11.4	17.1
260	no	9.7	11.4	13.2
246	yes	9.4	13.7	19.8

FIGURES

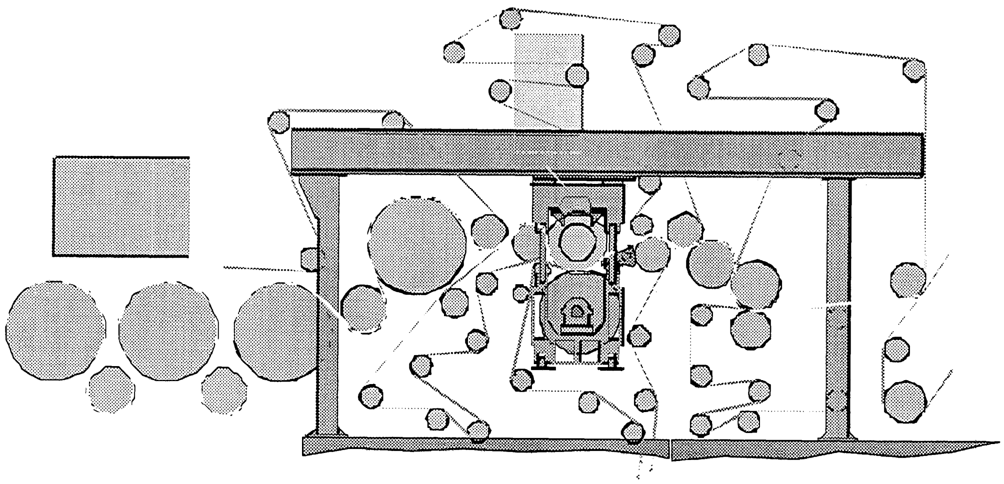

Figure 1. Press Section of the Pilot Paper Machine Showing the Impulse Dryer.

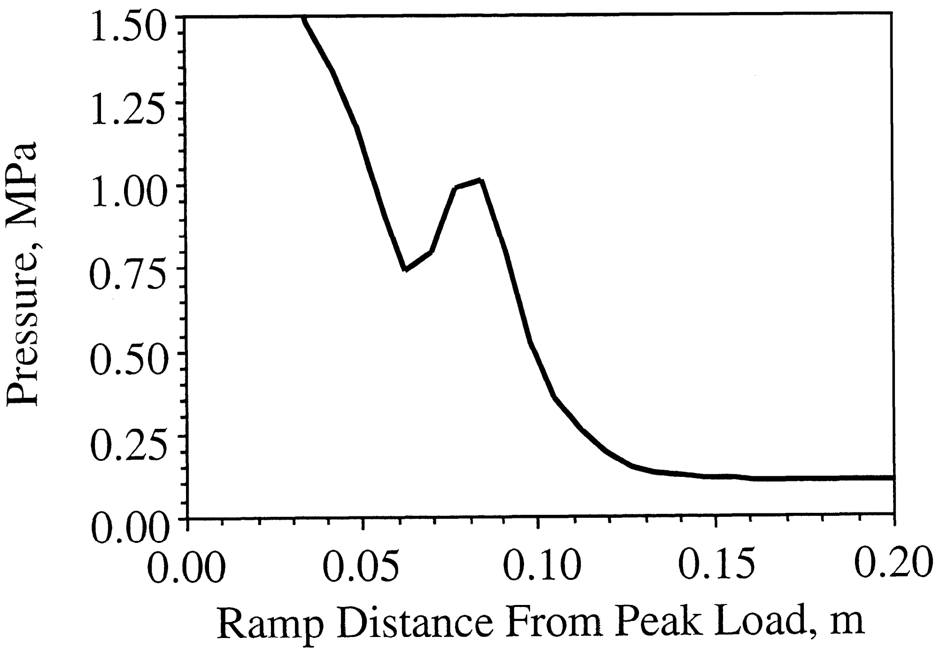

Figure 2. Ramp Pressure Profile.

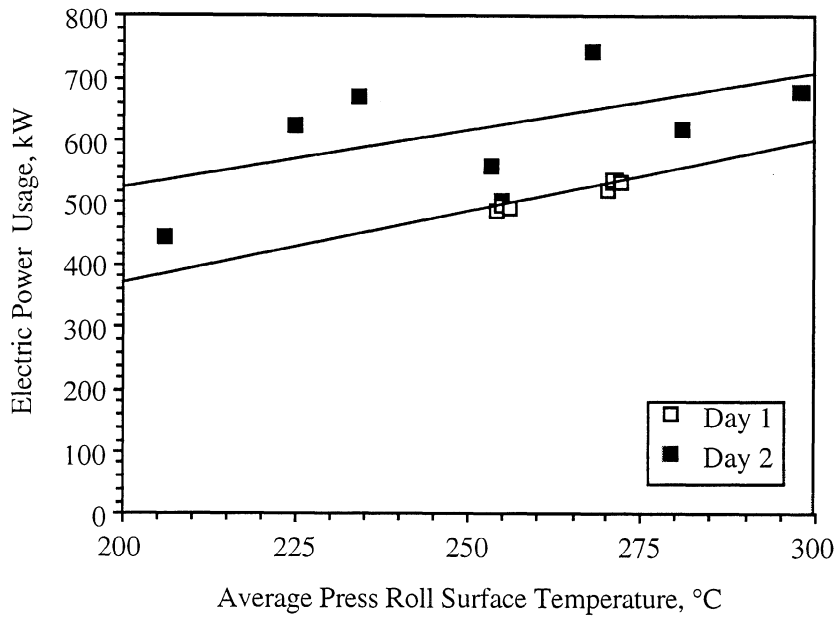

Figure 3. Electric Power Usage versus Average Press Roll Temperature.

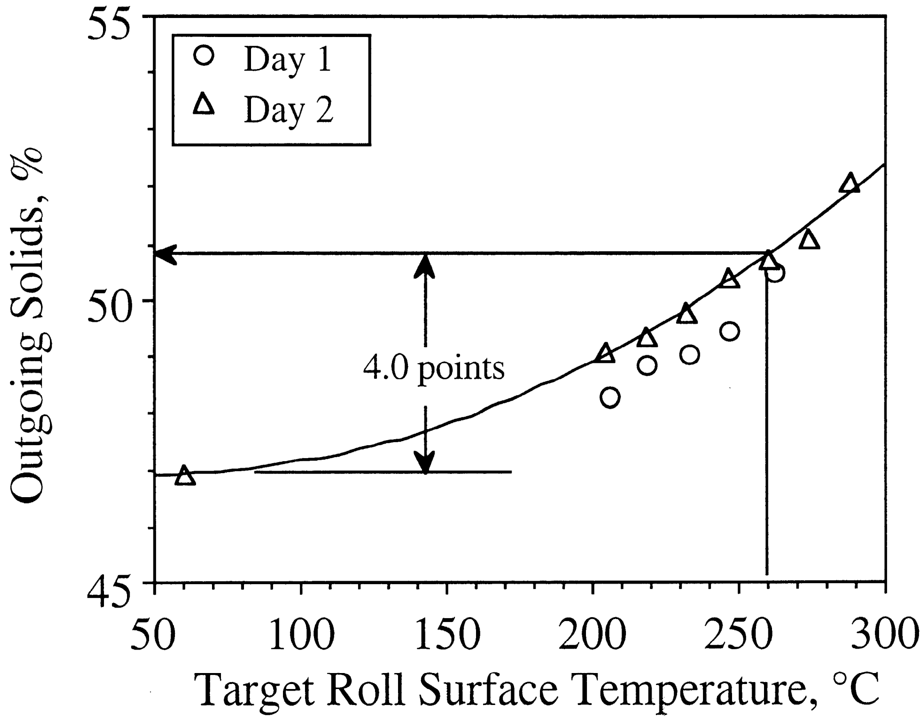

Figure 4. Outgoing Solids versus Target Roll Surface Temperature.

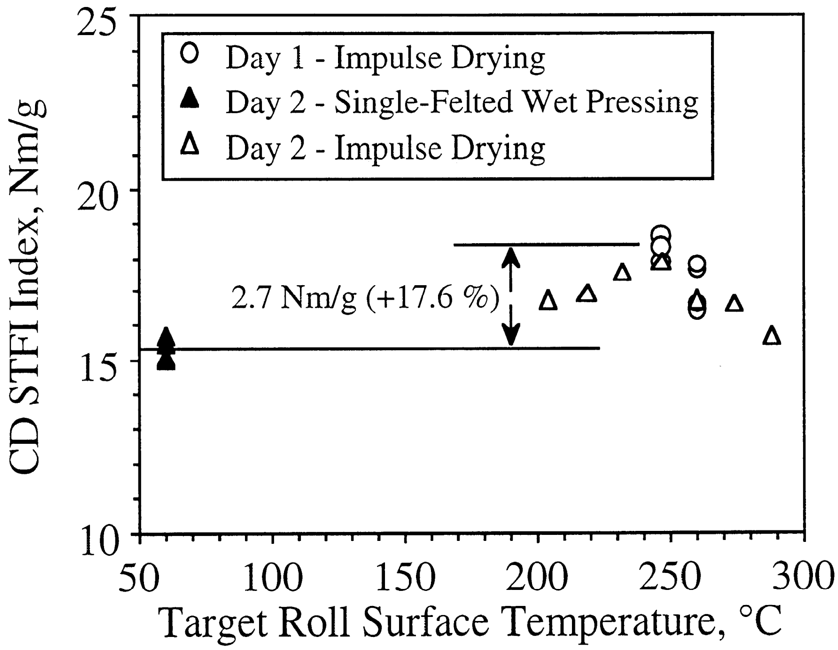

Figure 5. Preliminary Cross-Directional STFI Compression Strength Index versus Target Roll Surface Temperature.

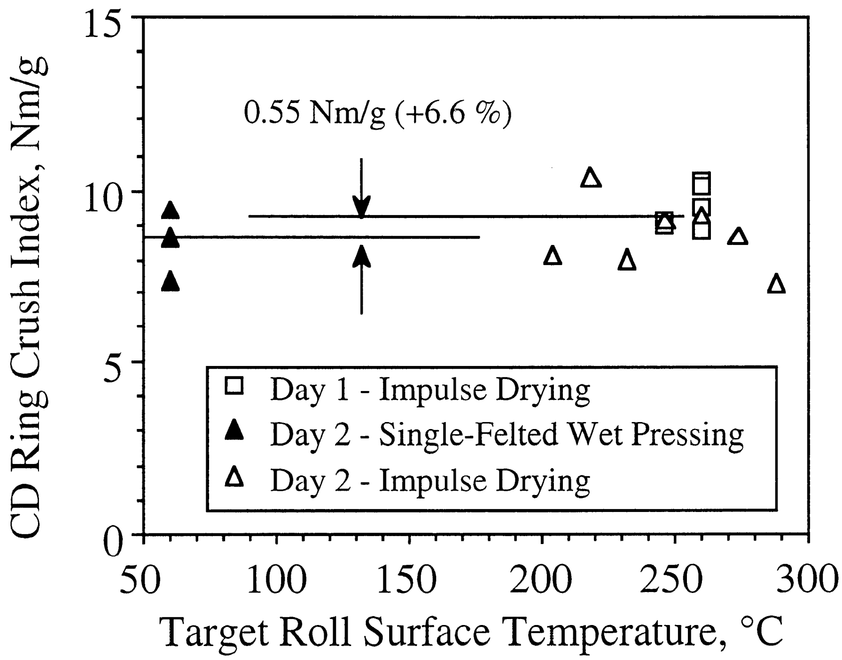

Figure 6. Preliminary Cross-Directional Ring Crush Index versus Target Roll Surface Temperature.

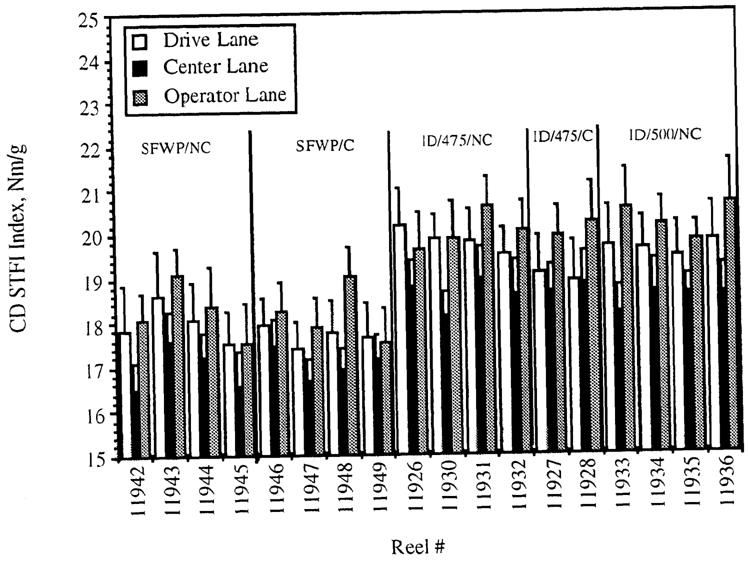

Figure 7. Cross-Directional STFI Index versus Reel Number

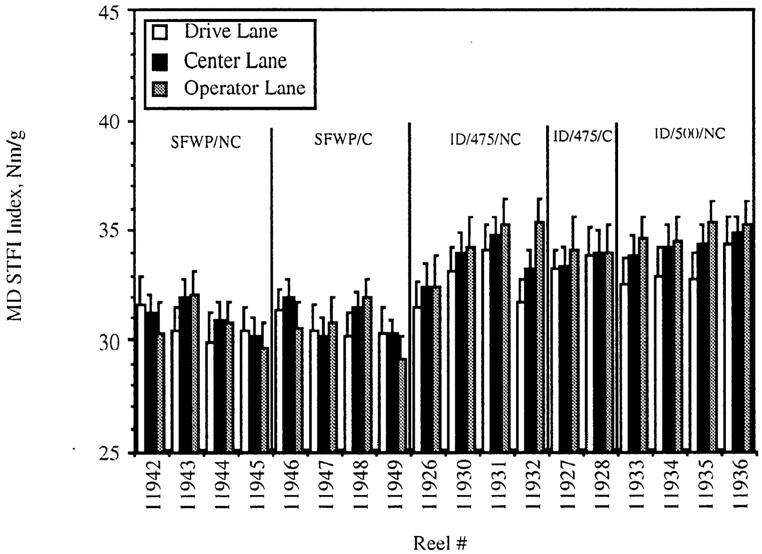

Figure 8. Machine-Directional STFI Index versus Reel Number

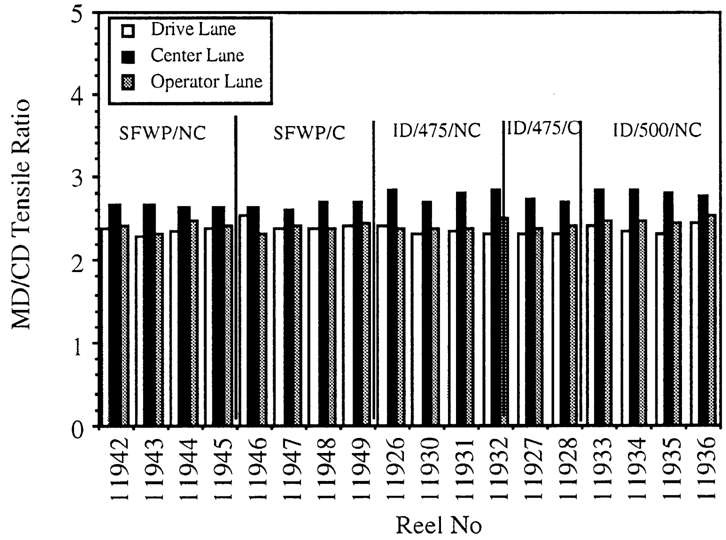

Figure 9. MD/CD Tensile Ratio Versus Reel Number

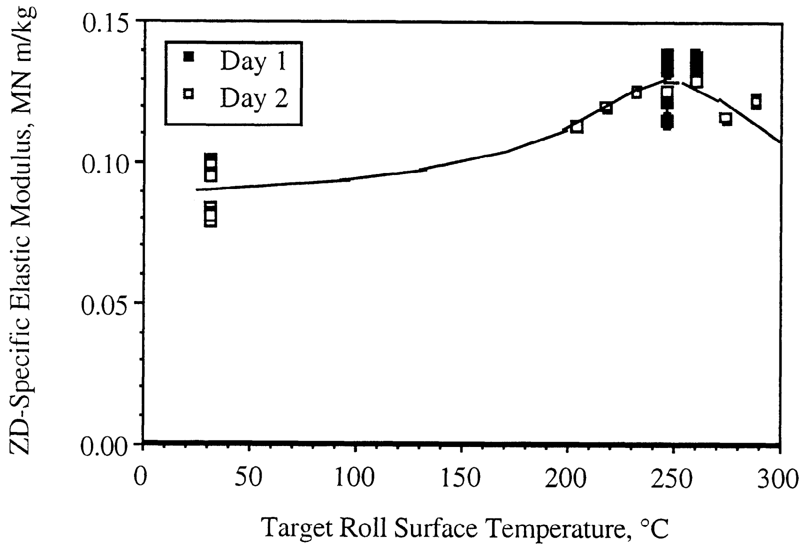

Figure 10. ZD- Specific Elastic Modulus versus Target Roll Surface Temperature.

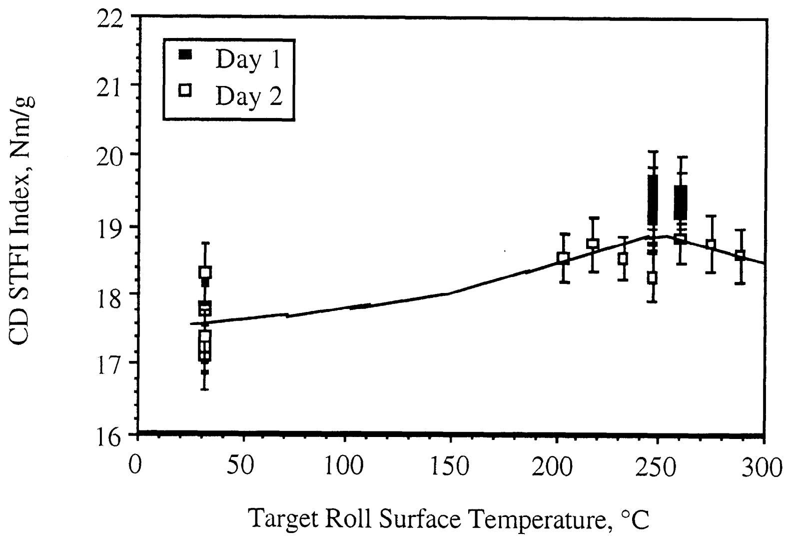

Figure 11. Cross-Directional STFI Compression Index versus Target Roll Surface Temperature.

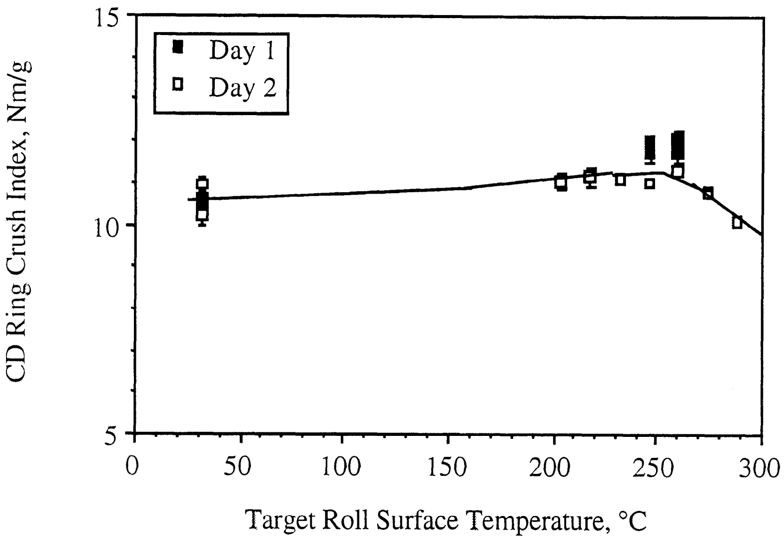

Figure 12. Cross-Directional Ring Crush Index versus Target Roll Surface Temperature.

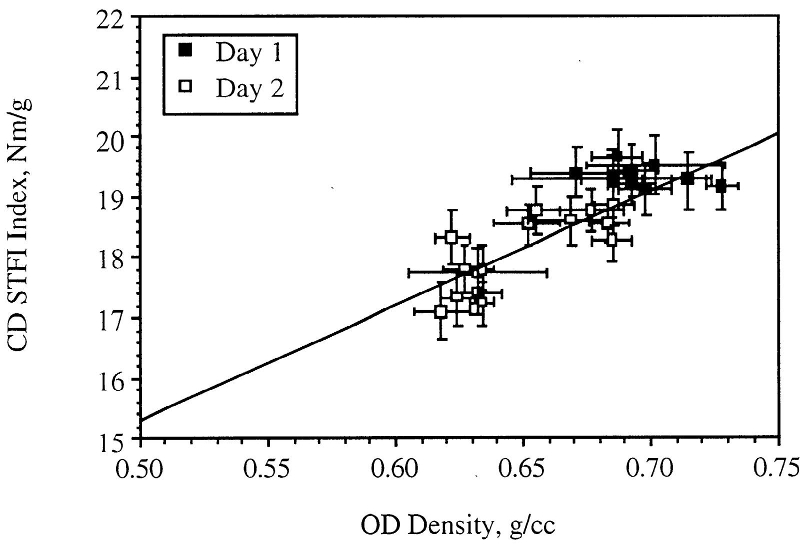

Figure 13. Cross-Directional STFI Compression Index versus OD Density.

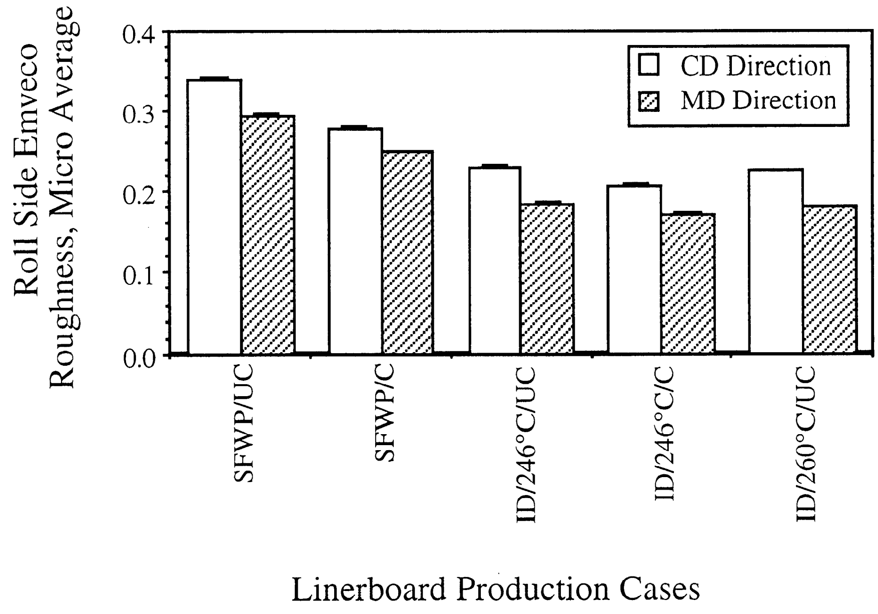

Figure 14. Micro Average Roll Side Emveco Roughness for Linerboard Production Cases.

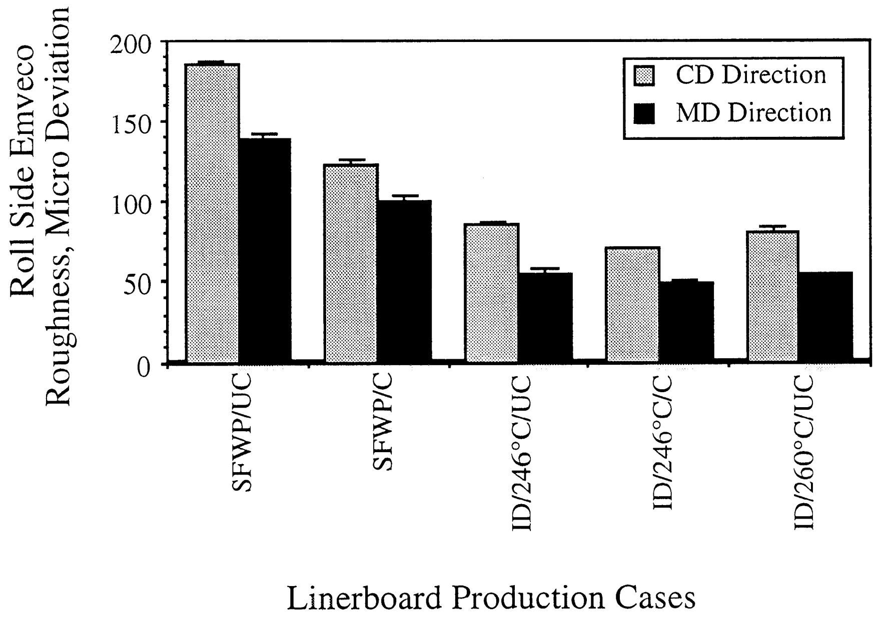

Figure 15. Micro Deviation Roll Side Emveco Roughness for Linerboard Production Cases.